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Research Paper

Weed dynamics and productivity of irrigated winter (*rabi*) castor (*Ricinus communis*) under integrated weed-management practices

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) season of 2012–13 to 2014–15 on Vertisols of Navsari, Gujarat, to study the effect of integrated weed-management practices on weed dynamics and productivity of winter (*rabi*) castor (*Ricinus communis* L.) under irrigated condition. The grassy weeds were dominant as compared to broad-leaf ones during the period of experimentation. Maintenance of weed-free condition [3 hand-weedings (HW) at 20, 40 and 60 days after sowing (DAS)] resulted in significant reduction in population of monocot, dicot and total weeds at 60 DAS. But, it remained at par with pre-emergence application of pendimenthalin 1.0 kg/ha + 2 hand-weedings at 40 and 60 DAS for density of monocots weeds. All the weed-management treatments recorded significantly lower weed dry matter at 120 DAS as compared to unweeded control and application of pendimenthalin 1.0 kg/ha as pre-emergence, followed by quizalofop-p-ethyl@ 0.05 kg/ha at 20 DAS as post-emergence. Similarly, significantly more number of branches, spikes and capsules/plant, spike length and seed yield were also recorded with pre-emergence application of pendimenthalin 1 kg/ha, followed by either 2 HW at 40 and 60 DAS or 1 HW at 40 DAS which remained statistically at par with weed-free condition. The weed-free condition (3 hand-weedings at 20, 40 and 60 DAS) accrued higher net returns (₹42.7 × 10^3/ha), closely followed by pendimethalin 1 kg/ha (pre-emergence) + HW at 40 and 60 DAS (₹42.2 × 10^3/ha) and pendimethalin 1 kg/ha (pre-emergence) + HW at 40 DAS (₹40.4 10^3/ha). However, higher benefit: cost (BCR) was recorded with pendimethalin 1 kg/ha (PE) + HW at 40 DAS (2.41), followed by pendimethalin 1 kg/ha (PE) + HW at 40 and 60 DAS (2.33).

Key words : Castor, Economics, Pendimenthalin, Seed yield, Weed management

Castor is an important non-edible oilseed crop of India, having immense industrial and commercial value. India is the world leader in its production followed by China and Brazil. Gujarat is the leading castor-growing state of our country. Of late, the area under this crop is increasing in south Gujarat reflecting its profitable cultivation. Weeds cause enormous crop losses and are one of the most important production constraints in south Gujarat due to high rainfall. Weeds also increase the problem of pests and diseases, as they acts as alternate hosts. Severe crop losses (up to 85 to 89%) have been observed due to weeds in castor crop also (Etagegnehu and Fufa, 2016). Weed menace in this crop is high due to wider crop space and its slow initial growth, conditions for availability of sunlight. This problem will be more under irrigated ecosystem due to availability of sufficient moisture. Several measures have been suggested to control the weeds. Hoe and hand-weeding on day 30 and day 60 after sowing are effective in removing the weeds. Hand-weeding and inter-culturing are effective, but always associated with regeneration of weeds and require frequent operations, which makes this practice sometimes costly and also not feasible all times due to poor soil physical condition and unavailability of labour and implements (Patel and Virdia, 2011). In this context, herbicides and other effective methods like mulching can play vital role in management of weeds. The use of herbicides in crop land, results in increase in crop yield, improve crop quality and reduce production cost besides timely control of weeds. Various methods of weed control do have restrictions in usage depending on the crop, soil and climate besides economics. Hence integrated weed management has gained importance. Since studies on integrated weed management and its impact on castor ecosystem are meager, the present study was carried

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with an objective to standardize the effective weed-management practices for castor under irrigated condition.

METHODS AND MATERIALS

A field experiment was conducted during the winter (*rabi*) season for 3 consecutive years, i.e. from 2012–13 to 2014–15 at Pulses and Castor Research Station, Navsari Agricultural University, Navsari (20° 57' N, 72° 54' E, 10 m above sea-level), Gujarat. The region has sub-tropical humid climate and receives annual rainfall of 1,400 mm and experiences mean annual maximum and minimum temperature of 43 and 10°C respectively. The soil is Vertisols with clayey texture, having *p*H 8.2, bulk density 1.42 g/cm^3, low organic carbon content (0.42%), low available nitrogen (230 kg/ha), medium in available phosphorus (40.2 kg/ha) and fairly rich in potash (310 kg/ha). Eight integrated weed-management practices, viz. pendimethalin @ 1.0 kg/ha (PE) with hand-weeding (HW) at 40 days after sowing (DAS), pendimethalin @ 1.0 kg/ha (PE) with HW at 40 and 60 DAS, weed-free through hand-weeding (HW) at 20, 40 and 60 DAS, farmer's practice (2 HW at 30 and 60 DAS), quizalofop ethyl @ 0.05 kg/ha (PoE) at 20 DAS + HW at 60 DAS, pendimethalin @ 1.0 kg/ha (PE) + Quizalofop ethyl @ 0.05 kg/ha (PoE) at 20 DAS, pendimethalin @ 1.0 kg/ha (PE) + Quizalofop ethyl @ 0.05 kg/ha (PoE) at 20 DAS + HW at 60 DAS and unweeded (control) were evaluated in a randomized block design (RBD) with 3 replications. Castor hybrid 'GCH 7' was used for the study. Crop was sown at a spacing of 120 cm × 60 cm. Nitrogen and phosphorus (120 : 25 kg N : P_2O_5/ha) were applied as per local recommendation in form of urea and diammonium phosphate respectively. Entire dose of P and one-third of total N were applied at the time of sowing and remaining dose of nitrogen was applied in 2 equal splits at 35 and 75 to 80 DAS. Irrigations, plant protection and other practices were followed as per recommendation for this region for healthy crop growth. Pendimethalin was applied as pre-emergence one day after sowing, whereas Quizalofop-ethyl was applied at 20 DAS as per treatment. Hand-weeding was done as per treatment with help of *khurpi*. An iron square of size 1 m^2 was used to take observation on weed population through random sampling in each plot at 60 DAS (just before hand weeding). The total number of monocot (including sedges) and dicot weeds were counted in each plot separately and analyzed after subjecting the original data to square-root transformation. For weed dry weight, weeds collected from 1 m^2 area at 120 DAS were dried under the sun and then in an oven at 65 °C for 42 h and weighed. Weed index (WI) was calculated as per following formula given by Nandekar (2005).

$$WI = \frac{(X-Y)}{X} \times 100$$

where WI, weed index; X, yield in weed-free plot; Y, yield under treatment for which WI is to be worked out.

Economics of treatments were computed on the basis of prevailing market price of inputs and outputs in Indian rupees under each treatment. The total cost of cultivation was calculated on the basis of different operations performed and materials used for raising crop. Statistical analysis of the data was done as per the standard analysis of variance technique and treatment means were compared at $P<0.05$ level of probability using t-test and calculating CD value. Bio-assay test at laboratory with sowing of greengram was done for examining the residual effect of herbicides used under study. Analysis of residue of herbicide (pendimenthalin) under best treatment in comparison to control was also carried out at the Food Quality Testing Laboratory, Navsari Agricultural University, Navsari, Gujarat using Soil QuEChERS method (AOAC Official Method-2007, pesticide residues in foods by acetonitrile extraction and partitioning with magnesium sulfate).

RESULTS AND DISCUSSION

Weed flora

The predominant common sedge and grassy weeds present in the experimental field were *Cyperus rotundus* (L.), *Cynodon dactylon* (L.) Pers. and *Echinochloa crusgalli* (L.) Beauv, while broad-leaf weeds present were *Triantherma portulacastrum* L., *Alternathera sessilis* (L.) R. Br. ex DC., *Digera arvensis* L. and *Convolvulus arvensis* L. etc. Nearly three-fourths of the weed infestation was dominated by grassy and sedge weeds followed by broad-leaf weeds (25%). Patel *et al.* (2014) also observed similar weed flora in castor field under south Gujarat conditions.

Weed density and dry weight of weeds

The density of monocot, dicot and total weeds at 60 DAS was affected significantly by different weed-management practices (Table 1). Significantly lower density of monocot, dicot and total weeds at 60 DAS was observed under weed-free treatment (3 hand-weedings at 20, 40 and 60 DAS) and it remained statistically at par with pre-emergence application of pendimenthalin 1.0 kg/ha along with 2 hand-weedings at 40 and 60 DAS for density of monocots weeds only. Density of monocot weeds was dominant over dicot weeds during the period of experimentation. Almost similar results were reported earlier by Singh *et al.* (2013) in castor. Significantly higher number of grassy, broad-leaf weeds and total weeds were recorded under unweeded treatment (control) as compared to the other treatments under test.

Weed-management treatments resulted in significant reduction in dry matter of weeds at 120 DAS of castor crop (Table 1). Application of pendimenthalin 1.0 kg/ha pre-emergence followed by 1 hand-weeding at 40 DAS recorded lower weed biomass over unweeded control and application of pendimenthalin 1.0 kg/ha as pre-emergence, followed by application of quizalofop-ethyl 0.05 kg/ha at 20 DAS as post-emergence. While the other treatments of weed management under study remained statistically at par with application of pendimenthalin 1.0 kg/ha as pre emergence + 1 hand-weeding at 40 DAS. The lower weed biomass under weed-management treatments might be due to poor weed growth. Vaghasia *et al.* (2015) were also reported similar results in castor.

Application of pendimenthalin 1.0 kg/ha as pre emergence + hand-weeding at 40 and 60 DAS, application of pendimenthalin 1.0 kg/ha as pre-emergence + hand-weeding at 40 DAS and weed-free treatment (3 hand-weedings at 20, 40 and 60 DAS) were found at par and recorded higher weed-control efficiency over the other treatments. Looking to weed index which is the indicator of losses in seed yield due to presence of weeds (Table 1), treatment weed-free up to harvesting was considered as base for calculating weed-competition index. Application of pendimenthalin 1.0 kg/ha as pre-emergence + hand-weeding at 40 and 60 DAS resulted in the lowest weed index. This might be due to effective weed control achieved under these treatments in terms of reduced biomass of weeds and higher weed control competence. Patel *et al.* (2014) were also reported the lowest weed index with treatment weed-free up to 120 DAS followed by the treatment weed-free up to 90 DAS.

Growth and yield attributes

Pooled data revealed that plant height of castor was not significantly influenced by different treatments under study. Higher number of branches/plant was observed under weed-free treatment which remained at par with pre-emergence application of pendimethalin 1 kg a.i./ha + either 2 HW at 40 DAS and 60 DAS or 1 HW at 40 DAS than the other treatments. This is attributed to better weed control under these treatments and reduction in the efficiency of weeds to compete for space, nutrition and moisture resulting in better plant growth and increased the number of branches/plant (Table 2).

Pre-emergence application pendimethalin 1 kg/ha as followed by either 2 HW at 40 and 60 DAS or 1 HW at 60 DAS were found equal to treatment of weed-free (3 hand-weedings at 20, 40 and 60 DAS) and superior to the other treatments for spike length, number of spikes/plant and number of capsules/spike. Weed-free environment condition facilitated better growth and development of crop resulted in enhancement of yield attributes. Patel and Virdia (2011) also reported that proper weed control also responsible for enhancing the yield attributes in castor. Test weight (100-seed weight) and oil content were non-significant.

Yield

Pooled results exhibited significant differences for seed

Table 1. Weed density, weed dry weight and weed-management indices under different weed-management practices in castor (pooled data of 3 years)

Treatment	Weed density at 60 DAS (No./m²)			Weed biomass (g/m²) at 120 DAS	Weed-control efficiency (%)	Weed index
	Monocot weeds	Dicot weeds	Total weeds			
T_1, Pendimethalin 1 kg/ha (PE) + HW at 40 DAS	5.12 (26.3)	3.07 (9.4)	5.97 (35.7)	279.0	45.9	11.0
T_2, Pendimethalin 1 kg/ha (PE) + HW at 40 and 60 DAS	4.74 (22.4)	2.91 (8.4)	5.56 (30.9)	280.7	46.0	4.9
T_3, Weed-free (HW at 20, 40 and 60 DAS)	4.51 (20.4)	2.54 (6.4)	5.17 (26.8)	285.0	45.9	0.0
T_4, 2 HW (at 30 and 60 DAS)/farmer's practice	4.94 (24.4)	2.96 (8.8)	5.76 (33.2)	348.3	34.1	24.0
T_5, Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	5.07 (25.7)	3.35 (11.2)	6.07 (36.9)	367.3	29.3	40.2
T_6, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS)	5.88 (34.6)	3.50 (12.2)	6.84 (46.8)	379.0	25.7	40.1
T_7, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	5.29 (28.0)	3.14 (9.9)	6.16 (37.9)	303.0	41.0	17.7
T_8, Unweeded control	6.43 (41.3)	3.87 (15.0)	7.51 (56.3)	515.7	0.0	47.0
SEm±	0.11	0.26	0.10	32.12	-	-
CD (P=0.05)	0.34	0.88	0.32	97.4	-	-

HW, Hand-weeding; DAS, days after sowing, PE, pre-emergence; PoE, post-emergence
Data subjected to $\sqrt{x}$ transformation, figures in parentheses are means of original values

Table 2. Growth and yield attributes as well as oil content of castor as influenced by different weed management practices (pooled data of 3 years)

Treatment	Plant height (cm)	Branches/ plant	Spike length (cm)	Spikes/ plant	Capsules/ spike	100-seed weight (g)	Oil content (%)
T_1, Pendimethalin 1 kg/ha (PE) + HW at 40 DAS	128.2	6.0	64.7	8.5	59.1	33.9	46.0
T_2, Pendimethalin 1 kg/ha (PE) + HW at 40 and 60 DAS	123.8	6.0	61.3	8.5	64.4	34.6	45.9
T_3, Weed-free (HW at 20, 40 and 60 DAS)	131.5	6.5	64.1	8.1	66.8	33.9	45.8
T_4, 2 HW (at 30 and 60 DAS)/farmer's practice	108.9	5.1	57.3	6.7	52.3	32.3	46.1
T_5, Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	100.9	4.0	50.0	5.6	40.4	32.6	45.2
T_6, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS)	128.7	4.0	51.6	5.4	42.7	34.3	45.8
T_7, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	120.2	4.6	58.3	5.4	51.5	34.3	46.1
T_8, Unweeded control	98.5	3.1	43.9	5.1	34.0	32.7	46.1
SEm±	9.37	0.33	1.91	0.47	5.0	0.72	0.38
CD (P=0.05)	NS	1.0	5.8	1.4	15.3	NS	NS

HW, Hand-weeding; DAS, days after sowing, PE, pre-emergence; PoE, post-emergence

yield of castor among the various integrated weed-management techniques (Table 3). Significantly higher seed yield was recorded (2,248 kg/ha) with 3 hand-weedings at 20, 40 amd 60 DAS over the other treatments except pre-emergence application of pendimethalin 1 kg/ha + 2 hand-weedings at 40 and 60 DAS and pendimethalin 1 kg/ha as pre-emergence + 1 hand-weeding at 40 DAS. The higher seed yield under these treatments was owing to better growth attributes, i.e. plant height and branches/plant, and yield attributes, i.e. spikes/plant, length of primary spike and capsules/spike (Table 2). Dungarwal *et al*. (2002) reported that, effectiveness of pre-emergence application of pendimethalin 1 kg/ha improved greatly when it was applied in combination with hoeing at 40 DAS in castor. Valdinei *et al.* (2012) also reported similar results for seed yield of castor.

Residual/ phytotoxic effect of pendimethalin

No residual/carry-over phytotoxicity of any herbicides was observed on succeeding greengram crop under bioassay study (Table 4). Further, result of residue analysis of pendimethalin in soil and seed of castor at laboratory (Table 5) indicated that there was no residue of pendimethalin in seed of castor and 0.029 ppm in soil which was below than European Commission approved maximum residue level (EU-MRL), i.e. 0.05 ppm.

Economics

Economics (Table 5) showed that weed-free condition (3 hand-weedings at 20, 40 and 60 DAS) accrued higher net returns (₹42.7 × 10^3/ha). It was closely followed by pendimethalin 1 kg/ha (pre-emergence) + HW at 40 and 60 DAS (₹42.2 × 10^3/ha) and pendimethalin 1 kg/ha (pre-emergence) + HW at 40 DAS (₹40.4 × 10^3/ha). However, higher benefit: cost (BCR) was recorded with pendimethalin 1 kg/ha (PE) + HW at 40 DAS (2.41), followed by pendimethalin 1 kg/ha (PE) + HW at 40 and 60 DAS (2.33). The cost of cultivation was high in weed-free treatment due to engagement of more numbers of labour, while in case of herbicide treatments, the minimum labour was used besides higher weed-control efficiency. Kalaichelvi and Kumar (2016) also reported higher B: C ratio with integration of pre-emergence herbicide with hand-weeding in castor.

Thus, pre-emergence application of pendimenthalin 1.0 kg a.i./ha + 1 hand-weeding at 40 days after sowing has been proved economically feasible and viable weed-management practice for irrigated winter (*rabi*) castor, considering the present condition of scarcity and high cost of labour under south Gujarat conditions.

Table 3. Seed yield and economics of different weed management practices in castor (pooled data of 3 years)

Treatment	Seed yield (t/ha)	Gross returns (×10³ ₹/ha)	Cost of cultivation (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio
T_1, Pendimethalin 1 kg/ha (PE) + HW at 40 DAS	2.06	69.1	28.7	40.4	2.41
T_2, Pendimethalin 1 kg/ha (PE) + HW at 40 and 60 DAS	2.20	73.9	31.6	42.2	2.33
T_3, Weed-free (HW at 20, 40 and 60 DAS)	2.24	75.2	32.6	42.5	2.30
T_4, 2 HW (at 30 and 60 DAS)/farmer's practice	1.76	59.2	29.6	29.5	2.00
T_5, Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	1.39	46.4	28.6	17.8	1.62
T_6, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS)	1.38	46.2	27.6	18.6	1.67
T_7, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	1.90	63.8	30.6	33.1	2.08
T_8, Unweeded control	1.23	41.0	23.6	17.4	1.74
SEm±	0.07	–	–	–	–
CD (P=0.05)	0.22	–	–	–	–

HW, Hand-weeding; DAS, days after sowing, PE, pre-emergence; PoE, post-emergence
Selling price: Seed, ₹33,550/tonne

Table 4. Results of bioassay study of different weed management treatments on succeeding mungbean (mean data of 3 years)

Treatment	Germinated plant counts/30 seeds sown	Root length (cm) at 15 DAS	Shoot length (cm) at 15 DAS
T_1, Pendimethalin 1 kg/ha (PE) + HW at 40 DAS	30	9.8	21.3
T_2, Pendimethalin 1 kg/ha (PE) + HW at 40 and 60 DAS	30	10.5	21.7
T_3, Weed-free (HW at 20, 40 and 60 DAS)	30	9.4	21.9
T_4, 2 HW (at 30 and 60 DAS)/farmer's practice	–	–	–
T_5, Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	30	10.0	21.6
T_6, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS)	30	10.8	21.8
T_7, Pendimethalin 1 kg/ha (PE) + Quizalofop ethyl 0.05 kg/ha (PoE at 20 DAS) + HW at 60 DAS	30	10.5	21.9
T_8, Unweeded control	–	–	–

HW, Hand-weeding; DAS, days after sowing, PE, pre-emergence; PoE, post-emergence

Table 5. Analysis report of residue of pendimethalin in soil and seed of castor after completion of experiment

Sample detail	Target pesticide	Results	Limit of (µg/ml)	Remark, if any quantification
Soil	Pendimethalin	0.029	0.005 µg/ml	EU-MRL 0.05 ppm
Soil (Control)	Pendimethalin	BDL	0.005 µg/ml	EU-MRL 0.05 ppm
Castor seed	Pendimethalin	BDL	0.05 µg/ml	EU-MRL 0.05 ppm
Castor seed (Control)	Pendimethalin	BDL	0.005 µg/ml	EU-MRL 0.05 ppm

BDL, Below detected level
EU MRL, European Commission-Maximum Residue Level

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